US011119689B2

(12) **United States Patent**
Kawamura et al.

(10) **Patent No.: US 11,119,689 B2**
(45) **Date of Patent: Sep. 14, 2021**

(54) **ACCELERATED DATA REMOVAL IN HIERARCHICAL STORAGE ENVIRONMENTS**

(71) Applicant: **International Business Machines Corporation**, Armonk, NY (US)

(72) Inventors: **Kousei Kawamura**, Tokyo (JP); **Koichi Masuda**, Tokyo (JP); **Takahiro Tsuda**, Tokyo (JP); **Sosuke Matsui**, Tokyo (JP); **Takeshi Nohta**, Tsukuba (JP); **Shinsuke Mitsuma**, Tokyo (JP)

(73) Assignee: **International Business Machines Corporation**, Armonk, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 259 days.

(21) Appl. No.: **15/979,927**

(22) Filed: **May 15, 2018**

(65) **Prior Publication Data**

US 2019/0354307 A1 Nov. 21, 2019

(51) **Int. Cl.**
G06F 12/00 (2006.01)
G06F 3/06 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 3/0652*** (2013.01); ***G06F 3/0608*** (2013.01); ***G06F 3/0664*** (2013.01); ***G06F 3/0682*** (2013.01)

(58) **Field of Classification Search**
CPC G06F 3/0608; G06F 3/061; G06F 3/0652; G06F 3/0664; G06F 3/0682; G06F 3/0686
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,789,161	B1	9/2004	Blendermann	
7,249,218	B2	7/2007	Gibble	
8,402,226	B1 *	3/2013	Faibish	G06F 12/0804 711/143
9,372,801	B2	6/2016	Beeston	
2005/0055512	A1 *	3/2005	Kishi	G06F 12/0804 711/135

(Continued)

OTHER PUBLICATIONS

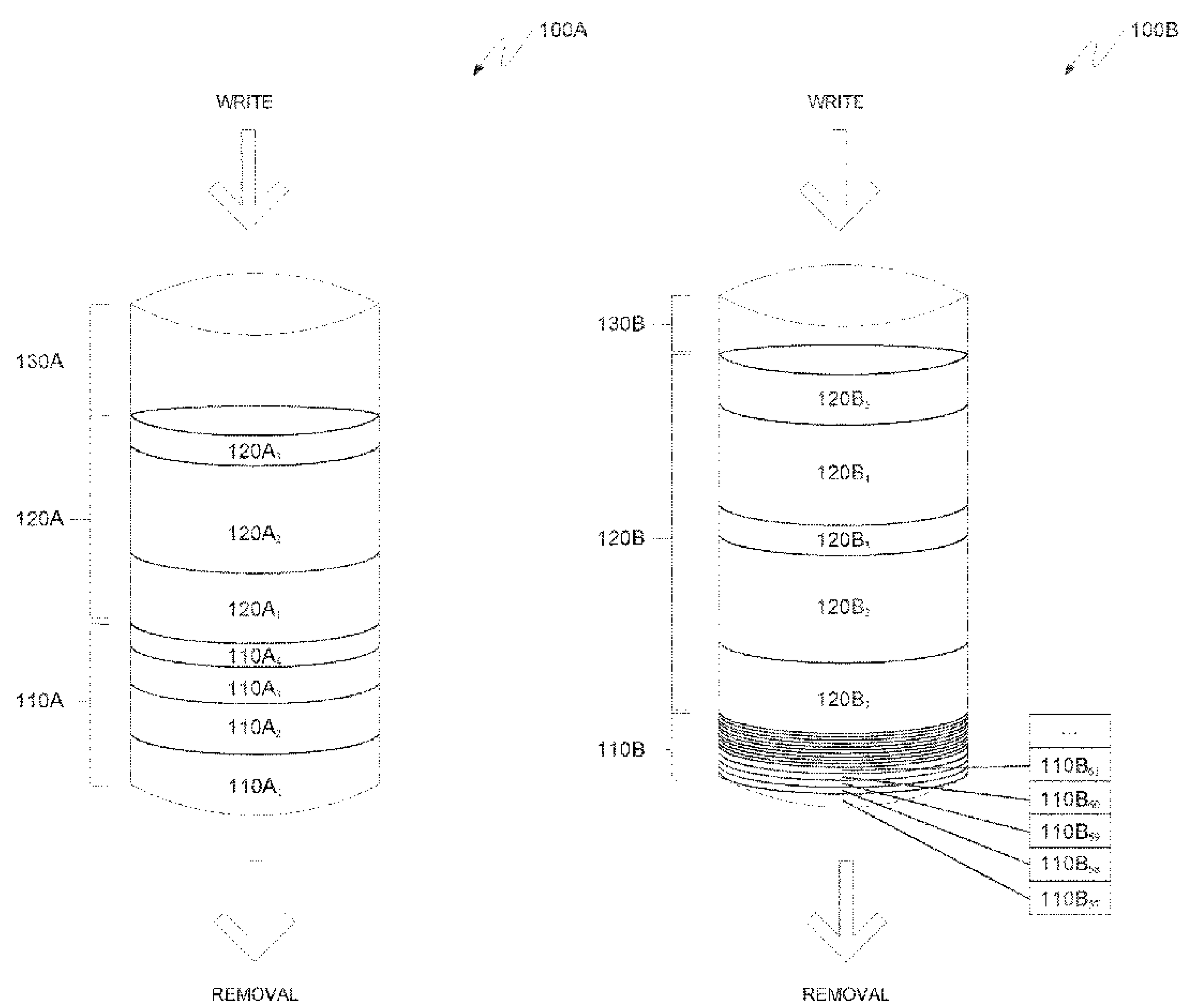
Kishi, G.T., "The IBM Virtual Tape Server: Making Tape Controllers More Autonomic", IBM J. Res. & Dev. vol. 47 No. 4 Jul. 2003, pp. 459-469.

Primary Examiner — Gurtej Bansal
(74) *Attorney, Agent, or Firm* — Aaron N. Pontikos

(57) **ABSTRACT**

A computer-implemented method for maintaining a storage volume in a virtual tape system includes writing one or more logical volumes associated with a first category and one or more logical volumes associated with a second category to a primary storage in a virtual tape system. The computer-implemented method further includes performing a first automatic removal process in order to free up space on the primary storage, wherein the first automatic removal process removes logical volumes associated with the first category in priority to logical volumes associated with the second category. The computer-implemented method further includes performing a second automatic removal process, wherein the second automatic removal process dynamically alters the priority of the first automatic removal process such that one or more virtual volumes associated with the second category are removed in priority to one or more virtual volumes associated with the first category.

16 Claims, 5 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

2005/0080992	A1*	4/2005	Massey	G06F 3/0605 711/114
2009/0222627	A1*	9/2009	Reid	G06F 12/0804 711/135
2010/0293328	A1	11/2010	Kishi	
2012/0284544	A1*	11/2012	Xian	G06F 3/061 713/320
2015/0331806	A1*	11/2015	Mondal	G06F 12/0246 711/103
2016/0259573	A1	9/2016	Brettell	

* cited by examiner

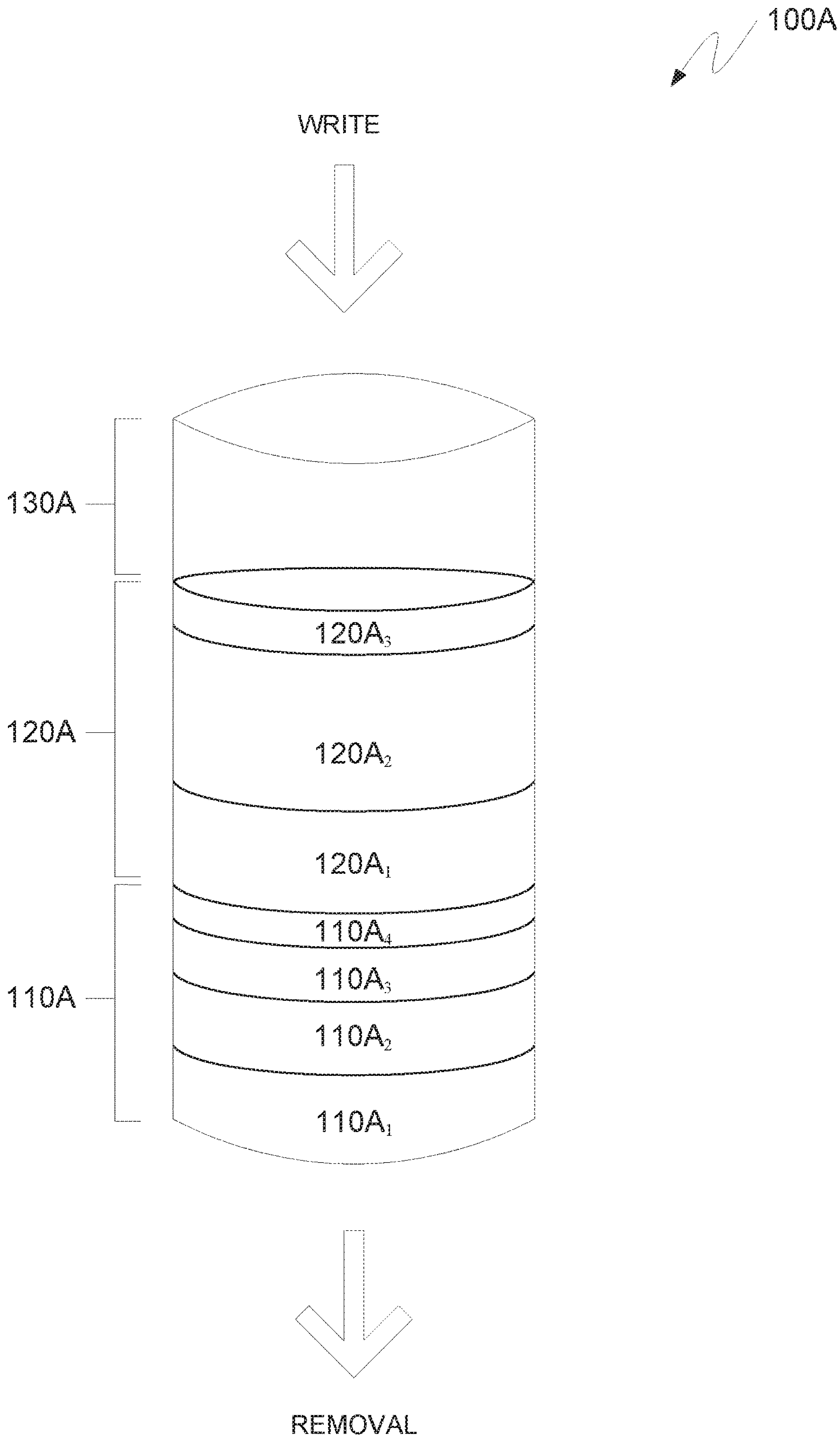

100A
WRITE
130A
120A
120A3
120A2
120A1
110A
110A4
110A3
110A2
110A1
REMOVAL

FIG. 1A

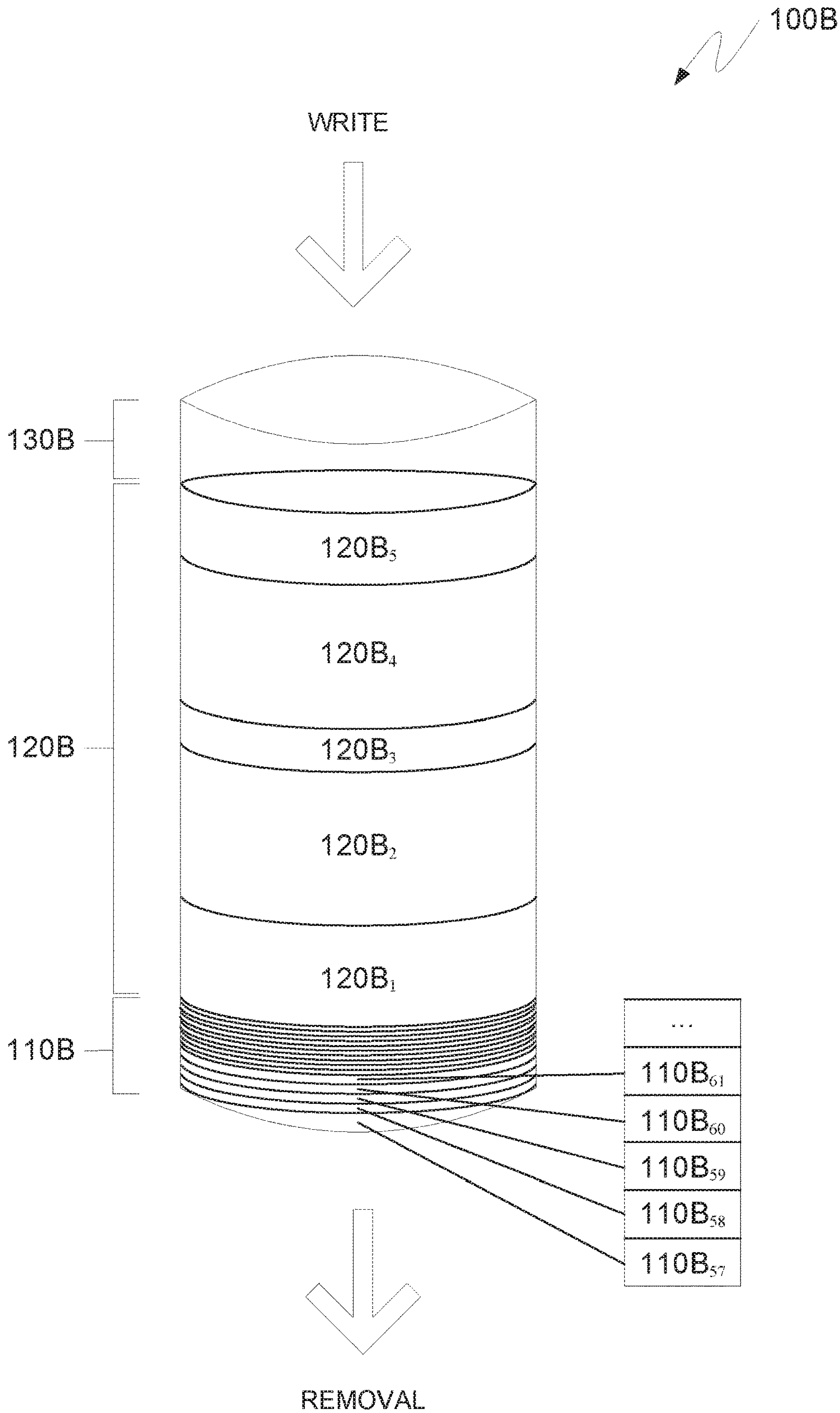

100B
WRITE
130B
120B
110B
120B5
120B4
120B3
120B2
120B1
...
110B61
110B60
110B59
110B58
110B57
REMOVAL

FIG. 1B

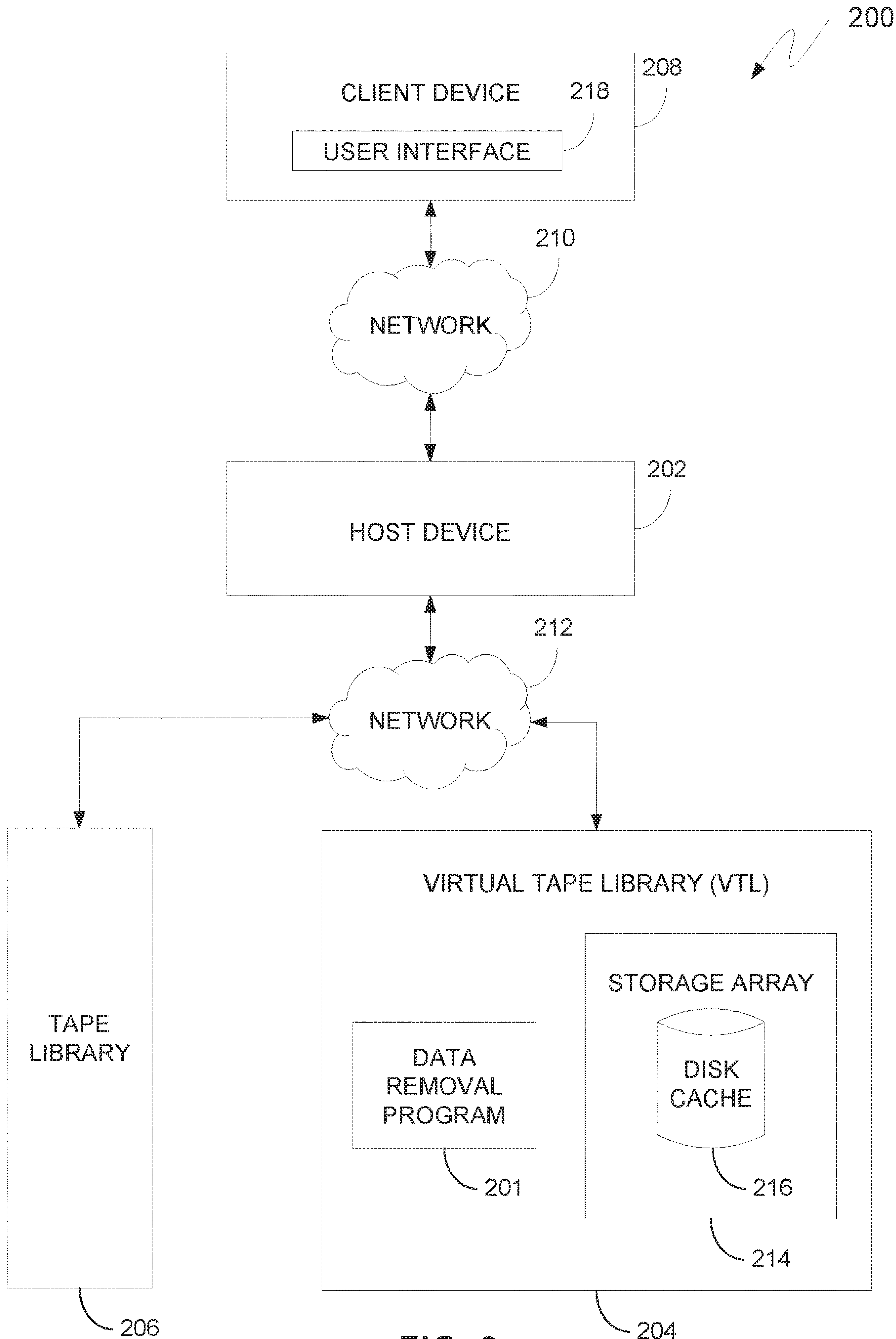

200
CLIENT DEVICE
218
208
USER INTERFACE
210
NETWORK
202
HOST DEVICE
212
NETWORK
VIRTUAL TAPE LIBRARY (VTL)
STORAGE ARRAY
TAPE LIBRARY
DATA REMOVAL PROGRAM
DISK CACHE
201
216
214
206
204

FIG. 2

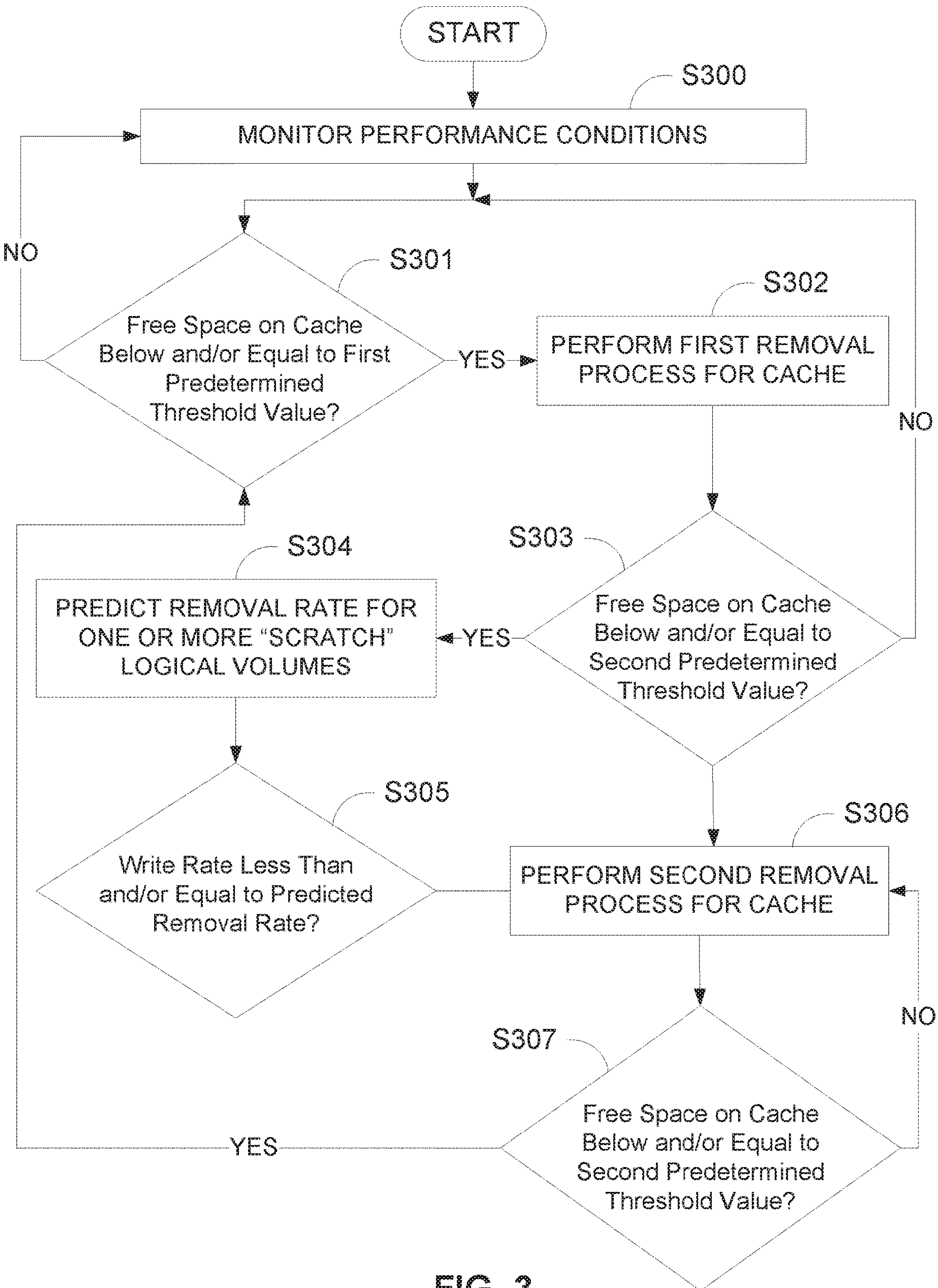

START
S300
MONITOR PERFORMANCE CONDITIONS
NO
S301
Free Space on Cache Below and/or Equal to First Predetermined Threshold Value?
YES
S302
PERFORM FIRST REMOVAL PROCESS FOR CACHE
NO
S303
Free Space on Cache Below and/or Equal to Second Predetermined Threshold Value?
YES
S304
PREDICT REMOVAL RATE FOR ONE OR MORE "SCRATCH" LOGICAL VOLUMES
S305
Write Rate Less Than and/or Equal to Predicted Removal Rate?
S306
PERFORM SECOND REMOVAL PROCESS FOR CACHE
NO
S307
Free Space on Cache Below and/or Equal to Second Predetermined Threshold Value?
YES

FIG. 3

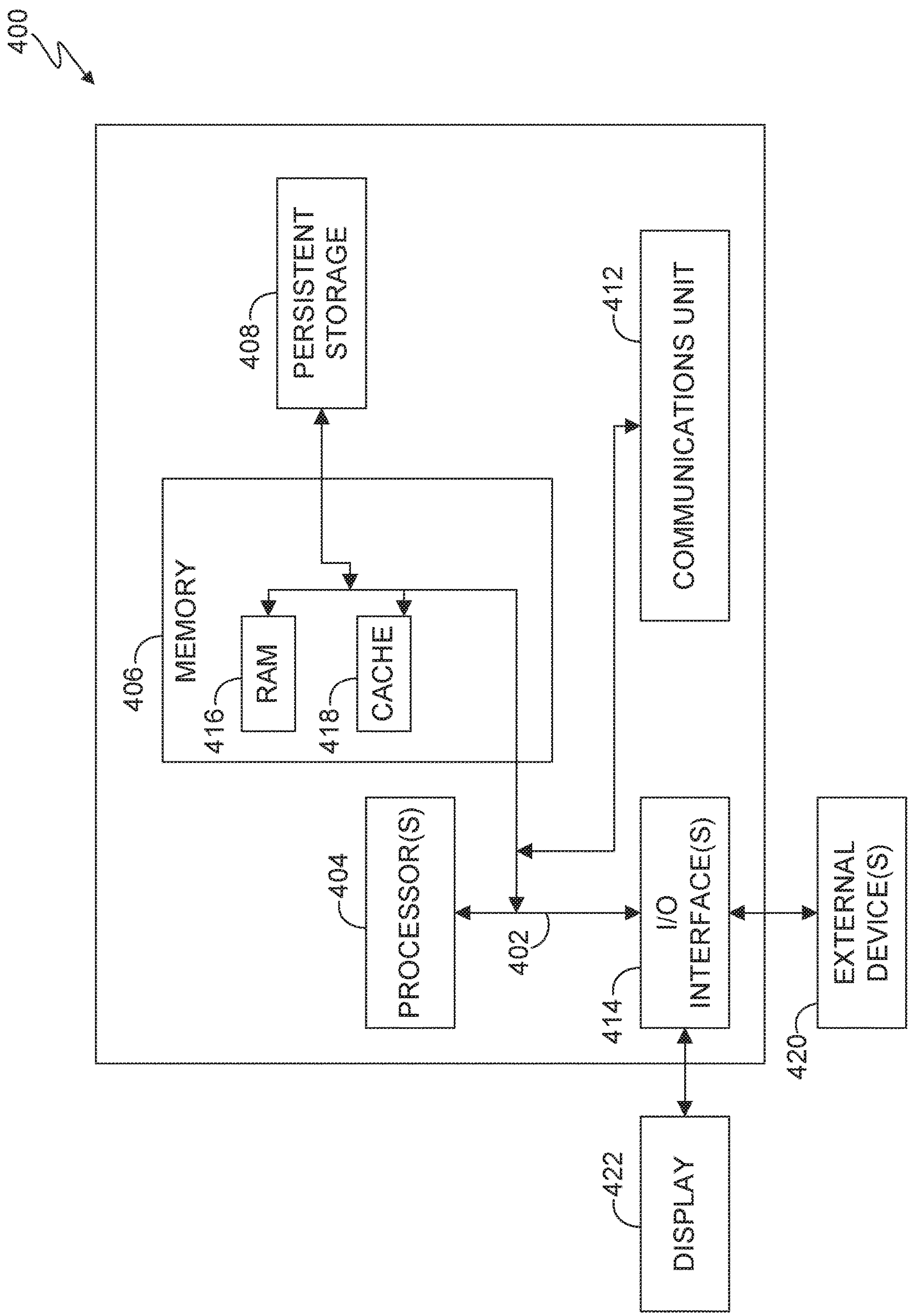

400
408
PERSISTENT STORAGE
406
MEMORY
416
RAM
418
CACHE
412
COMMUNICATIONS UNIT
404
PROCESSOR(S)
402
414
I/O INTERFACE(S)
420
EXTERNAL DEVICE(S)
422
DISPLAY

FIG. 4

ACCELERATED DATA REMOVAL IN HIERARCHICAL STORAGE ENVIRONMENTS

BACKGROUND

The present invention relates generally to the field of hierarchical storage management, and more particularly to hierarchical storage management of virtual tape systems.

Hierarchical storage management is a data storage process that moves data within a tiered storage environment. In a tiered storage environment, at least two types of data storage media are delineated by differences in attributes, such as price, performance, capacity, and function. Accordingly, whether data is stored in one tier or another is defined by the requirements of the data to be stored.

The use of hierarchical storage management allows an enterprise to reduce the cost of data storage, as well as simplify the retrieval of data from slower storage media. Typically, hierarchical storage management is used for deep archival storage of data that is required to be maintained for a prolonged period at low cost. The need for hierarchical storage management stems from the fact that high-speed storage devices (e.g., solid state drive arrays) are more expensive (per byte stored) than slower speed storage devices (e.g., hard disk drives, optical discs, and magnetic tape drives). With hierarchical storage management, infrequently used data files stored on high-speed storage media are migrated to slower speed storage media if the data files are not used (i.e., accessed) for a certain period. When access to the data files is required, data is copied from the slower speed storage to faster disk drives. In effect, hierarchical storage management turns a fast disk drive into a cache for the slower mass storage devices.

A virtual tape system ("VTS") is a cloud or virtual data storage and backup system that uses magnetic-tape-based consolidated storage infrastructure to store and retrieve data. A VTS functions like a typical magnetic tape storage system but is enabled and integrated with cloud storage and virtualization techniques. Typically, a VTS is implemented to achieve enhanced storage management performance while reducing disk cartridge waste. A VTS eliminates data retrieval latency by storing an instance of frequently used files in disk caches to provide faster access to the data. Moreover, a VTS uses a virtual tape library ("VTL") built over storage virtualization to reduce the amount of tape disk required.

SUMMARY

According to one embodiment of the present invention, a computer-implemented method for maintaining a storage volume in a virtual tape system is disclosed. The computer-implemented method includes writing one or more logical volumes associated with a first category and one or more logical volumes associated with a second category to the primary storage in the virtual tape system. The computer-implemented method further includes performing a first automatic removal process in order to free up space on the primary storage, wherein the first automatic removal process removes logical volumes associated with the first category in priority to logical volumes associated with the second category. The computer-implemented method further includes performing a second automatic removal process, wherein the second automatic removal process dynamically alters the priority of the first automatic removal process such that one or more virtual volumes associated with the second category

are removed in priority to one or more virtual volumes associated with the first category.

According to another embodiment of the present invention, a computer program product for maintaining a storage volume in a virtual tape system is disclosed. The computer program product includes one or more computer readable storage media and program instructions stored on the one or more computer readable storage media. The program instructions include instructions to write one or more logical volumes associated with a first category and one or more logical volumes associated with a second category to the primary storage in the virtual tape system. The program instructions further include instructions to perform a first automatic removal process in order to free up space on the primary storage, wherein the first automatic removal process removes logical volumes associated with the first category in priority to logical volumes associated with the second category. The program instructions further include instructions to perform a second automatic removal process, wherein the second automatic removal process dynamically alters the priority of the first automatic removal process such that one or more virtual volumes associated with the second category are removed in priority to one or more virtual volumes associated with the first category.

According to another embodiment of the present invention, a computer system for maintaining a storage volume in a virtual tape system is disclosed. The computer system includes one or more computer system includes one or more computer processors, one or more computer readable storage media, and program instructions stored on the computer readable storage media for execution by at least one of the one or more processors. The program instructions include instructions to write one or more logical volumes associated with a first category and one or more logical volumes associated with a second category to the primary storage in the virtual tape system. The program instructions further include instructions to perform a first automatic removal process in order to free up space on the primary storage, wherein the first automatic removal process removes logical volumes associated with the first category in priority to logical volumes associated with the second category. The program instructions further include instructions to perform a second automatic removal process, wherein the second automatic removal process dynamically alters the priority of the first automatic removal process such that one or more virtual volumes associated with the second category are removed in priority to one or more virtual volumes associated with the first category.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is an exemplary disk cache in a storage array of a virtual tape library in accordance with at least one embodiment of the invention.

FIG. **1**B is an exemplary disk cache in a storage array of a virtual tape library after undergoing a first logical volume auto-removal process over a period of time in accordance with at least one embodiment of the invention.

FIG. **2** is a functional block diagram of a network computing environment, generally designated **200**, suitable for operation of a data removal program **201** in accordance with at least one embodiment of the invention.

FIG. **3** is a flow chart diagram depicting operational steps for a data removal program **201** in accordance with at least one embodiment of the invention.

FIG. **4** is a block diagram depicting components of a computer, generally designated **400**, suitable for executing data removal program **201** in accordance with at least one embodiment of the invention.

DETAILED DESCRIPTION

Generally, a VTS includes a system (e.g., a special storage device, group of devices, etc.) and software, firmware, etc., that has hierarchical storage management functionality, whereby data is migrated between tiered storage. For example, a VTS migrates data between a primary, high-speed storage media (e.g., hard disk drives and/or solid-state disk drives) and a secondary, slower speed storage media (e.g., magnetic tape drive). The primary storage media (typically the faster storage device) is also known as a tape volume cache ("TVC").

A virtual tape library ("VTL") is a data storage virtualization technology that utilizes a storage component (usually hard disk storage) as tape libraries or tape drives for use with existing backup software. Virtualizing the disk storage as tape allows integration of VTLs with existing backup software and existing backup and recovery processes and policies. In essence, a VTL writes data in such a way that the data appears to be stored entirely on tape cartridges when the data is actually located on faster storage devices, such as solid-state drives and hard disk drives. A VTL can be thought of as a disk array that mimics tape. To servers, the VTL appears to be a tape library and the data backup software that writes to it and manages it as if it were tape. However, because a VTL is actually disk-based, it is much faster than tape to read and write. The benefits of such virtualization include storage consolidation and faster data restore processes. Furthermore, by backing up data to disks instead of tapes, VTL often increases performance of both backup and recovery operations.

A VTL stores data on disk drives as logical volumes (i.e., "virtual volumes"). In some instances, logical volumes are classified and managed according to categories of data. Such categories may include but are not limited to a "scratch" category and a "private" category. A scratch category is a category for registering logical volumes that are allowed to be overwritten. Thus, when writing new data to a VTL, the writer of the data performs a scratch mount. Upon receiving a scratch mount instruction, the VTL selects one of the volumes in the scratch category and performs the mount. In other words, the VTL selects a volume that can be overwritten.

The private category is a category for registering logical volumes that are not allowed to be overwritten and thus, are to be retained. Whether or not a logical volume is designated at a "scratch" or a "private" category can be designated by a user or system administrator. Additionally, a user or system administrator may change the designation, such that a logical volume with a "scratch" category can be moved to a "private" category and vice versa. Accordingly, a logical volume designated in the "private" category that is no longer needed can ultimately be moved from the "private" category to the "scratch" category.

Turning now to the Figures, and particularly to FIG. **1**A, an exemplary disk cache **100**A of a disk in a storage array of a VTL can be seen. As depicted in FIG. **1**A, disk cache **100**A includes a first category **110**A of stored data ("scratch" logical volumes), a second category **120**A of stored data ("private" logical volumes), and free space **130**A. First category **110**A of stored data includes scratch data **110**A_1, scratch data **110**A_2, scratch data **110**A_3, and scratch data **110**A_4. Second category **120**A of stored data includes private data **120**A_1, private data **121**A_2, and private data **122**A_3. As data is written to disk cache **100**A, free space **130**A decreases.

Once free space **130**A on disk cache **100**A is equal to and/or below a predetermined threshold value, the VTL is triggered to perform logical volume auto-removal processing in an attempt to increase free space **130**A on disk cache **100**A. According to typical logical volume auto-removal processes, logical volumes in the scratch category are first removed in descending order of capacity (i.e., size) so that free space can be provided faster. Thus, the order of removal (in descending order of capacity) of logical volumes in the scratch category of disk cache **100**A would be scratch data **110**A_1, scratch data **110**A_2, scratch data **110**A_3, and lastly scratch data **110**A_4. If all of the logical volumes in the scratch category have been removed, then logical volumes in the private category are removed in descending order of elapsed time of prior access.

FIG. **1**B illustrates an exemplary disk cache **100**B of a disk in a storage array of a VTL after undergoing a first type of logical volume auto-removal process over a period of time. It should be noted that disk cache **100**A is identical to disk cache **100**B. However, a portion of the data written to disk cache **100**B is different than the data written to disk cache **100**A as a result of logical volume auto-removal processing.

As depicted in FIG. **1**B, disk cache **100**B includes first category **110**B of stored data (logical volume scratch data), a second category **120**B of stored data (logical volume private data), and free space **130**B. Although scratch data **110**A_1, scratch data **110**A_2, scratch data **110**A_3, and lastly scratch data **110**A_4 have been removed from disk cache **100**A (depicted in FIG. **1**A), and thus are no longer stored on disk cache **100**B, as scratch data is removed from disk cache **100**A during the logical volume auto-removal process, new scratch data, as well as new private data is also being written to disk cache **100**A. Accordingly, first category **110**B of stored data on disk cache **100**B now includes scratch data **110**B_{57}, **110**B_{58}, and **110**B_{59} . . . **110**B_n. It should be noted that initially, as the larger capacity logical volumes in the scratch category are removed, free space on the disk cache increases. This is evinced by the fact that after undergoing logical volume auto-removal processing, second category **120**B of stored data of disk cache **100**B now includes private data **120**B_1, private data **120**B_2, private data **120**B_3, private data **120**B_4, and private data **120**B_5, wherein private data **120**B_1, private data **120**B_2, private data **120**B_3 is the same data as private data **120**A_1, private data **120**A_2, private data **120**A_3 of disk cache **100**A (depicted in FIG. **1**A).

However, with increasing demand for faster, more powerful and more efficient ways to store information, optimization of storage technologies remains a key challenge in VTSs. Embodiments of the present invention recognize several deficiencies with the first type of logical volume auto-removal process. Although logical volumes in the scratch category are removed in descending order of logical volume capacity (and thereby providing cache free disk space more quickly), the time required for removal of logical volumes is fixed, regardless of a logical volume's capacity.

As illustrated by FIGS. **1**A and **1**B, as logical volumes in the scratch category are removed in descending order of capacity (i.e., the larger capacity logical volumes are removed first), logical volumes with a smaller capacity remain on the disk cache. This stems from the fact that new, larger capacity logical volumes will continue to be mounted to the disk cache during the logical volume auto-removal process. As evinced by the transformation of the initial data stored on disk cache **100**A of FIG. **1**A at the start of the logical volume auto-removal process and the final data stored on disk cache **100**B after a period of time, the number of logical volumes in the scratch category on disk cache **100**B has actually increased.

Embodiments of the present invention recognize that since the time required for removal of a logical volume is fixed, regardless of the logical volume's capacity, the amount of cache free disk space that can be freed up decreases as the size of the logical volume being removed decreases. As the number of small capacity logical volumes loaded on the disk cache increases, the amount of cache free disk space created by the removal of such small capacity logical volumes becomes negligible. Accordingly, the amount of cache free disk space that can be freed up per unit of time (i.e., the rate of removal) through typical logical volume removal processes ultimately decreases over time.

If the rate of removal continues to be slower than the rate at which data is written, the disk will eventually run out of cache free disk space. The decrease in the rate of removal due to an increase in small capacity logical volumes in the scratch category becomes increasingly problematic if the disk runs out of cache free disk space. At this point, data writing to the VTS can no longer be performed and consequently, host jobs are suspended.

Embodiments of the present invention provide one or more of: features, characteristics, operations and/or advantages to the first type of logical volume auto-removal process and generally encompass (i) an improvement to at least the field of hierarchical storage management and (ii) a technical solution to one or more of challenges in the field of hierarchical storage management. Such challenges in the field of hierarchical storage management may include, but are not limited to, one or more of: (i) limitations in the amount of cache free disk space that can be freed up per unit of time, (ii) limitations in the removal of logical volumes in a private category, (iii) limitations in the data removal rate from a disk cache, and (iv) shifting respective priority of data removal in various logical volumes. Certain embodiments of the present invention both recognize and address other challenges that are not specifically addressed herein but are readily understood to be encompassed by the technical solutions described herein.

Embodiments of the present invention may increase the data removal rate from a disk cache (and thereby increase the amount of cache free disk space that can be freed up per unit of time) by removing logical volumes in the private category. Embodiments of the present invention increase the data removal rate from a disk cache by dynamically (i.e., automatically) shifting priority of data removal from logical volumes in the "scratch category" to logical volumes in the "private category" during a logical volume auto-removal process. In an embodiment, in response to shifting the priority of data removal, logical volumes in the private category are removed in descending order of elapsed time of prior access. In an embodiment, in response to shifting the priority of data removal, logical volumes in the private category are removed in descending order of capacity.

In embodiments of the invention, the priority of data removal is dynamically shifted based, at least in part, on one or more of the following factors: (i) a rate at which data is being written to the disk cache, (ii) a rate of removal (bytes per unit time) of data from the scratch category, and (iii) an amount of free space on the disk cache. In an embodiment, priority of data removal is dynamically shifted from logical volumes in the scratch category to logical volumes in the private category in response to determining that a rate of removal of logical volumes from the scratch category is below and/or equal to a predetermined threshold value. In a further embodiment, priority of data removal is dynamically shifted from logical volumes in the scratch category to logical volumes in the private category in response to determining that an amount of free space on a disk cache falls below a predetermined threshold value. In yet another embodiment, priority of data removal is dynamically shifted from logical volumes in the scratch category to logical volumes in the private category in response to determining that both the rate of removal of logical volumes in the scratch category and the amount of free space on a disk cache has fallen below a predetermined threshold value.

Similarly, embodiments of the present invention provide for dynamically shifting priority of data removal from logical volumes in the private category to logical volumes in the scratch category in response determining that an amount of cache free disk space on the TVC is above the predetermined threshold value.

In some embodiments of the invention, an increase in the data removal rate from a disk cache is accomplished without entirely shifting priority of data removal from logical volumes in the "scratch category" to logical volumes in the "private category." In these embodiments, priority of data removal from logical volumes in the "scratch category" is changed such that priority of data removal is alternated between logical volumes in the scratch category and logical volumes in the private category. In an embodiment, priority of data removal is restored entirely to the removal of logical volumes in the "scratch category" in response to determining that an amount of cache free disk space on the TVC exceeds a predetermined threshold value. In a further embodiment, priority of data removal is restored entirely to the removal of logical volumes in the "scratch category" in response to determining that a data removal rate exceeds a rate at which data is written to a disk cache.

Embodiments of the present invention recognize that although removing logical volumes in the private category may result in a decrease in the performance (due to cache misses) of host systems, the removal of logical volumes in the private category only occurs for a brief period of time (removal of even a single "private" logical volume will likely free up a large amount of space on the disk cache). Moreover, embodiments of the present invention generate a large amount of free space quickly when the amount of free space on a disk cache becomes scare, thereby averting a worst-case scenario where the disk cache becomes completely full. At this point, read/write operations cannot be performed, and application operations are suspended. Thus, embodiments of the present invention provide a technical solution that generates a net gain in overall performance for the computing system; i.e., the overall amount of computing resources that are consumed over time is decreased when compared to alternative solutions. Such computing resources may include but are not limited to central processor usage, volume of storage, network capacity, and the like. Those having skill in the art will recognize that embodiments of the present invention may reduce the strain, i.e. resource consumption, experienced by one or both of hierarchical storage systems as well as hierarchical storage managers when compared to alternative solutions.

Referring now to various embodiments of the invention in more detail, FIG. **2** is a functional block diagram of a network computing environment, generally designated **200**, suitable for operation of a data removal program **201** in accordance with at least one embodiment of the invention. FIG. **2** provides only an illustration of one implementation and does not imply any limitations with regard to the environments in which different embodiments may be implemented. Many modifications to the depicted environment may be made by those skilled in the art without departing from the scope of the invention as recited by the claims.

Network computing environment **200** includes host device **202**, virtual tape library **204**, tape library **206**, and client device **208** interconnected over network **210** and network **212**. In embodiments of the invention, network **210** can be a telecommunications network, a local area network (LAN), a wide area network (WAN), such as the Internet, or a combination of the three, and can include wired, wireless, or fiber optic connections. In embodiments of the invention, network **212** is a storage area network ("SAN"). Network **212** provides block-level network access to storage, such as virtual tape library **204** and tape library **206**. Network **210** and network **212** may include one or more wired and/or wireless networks that are capable of receiving and transmitting data, voice, and/or video signals, including multimedia signals that include voice, data, and video information. In general, network **210** and network **212** may be any combination of connections and protocols that will support communications between client device **208**, host device **202**, virtual tape library **204**, tape library **206**, and other computing devices (not shown) within network computing environment **200**.

In various embodiments of the invention, each of host device **202** and virtual tape library **204** are computing devices that can be a standalone device, a management server, a web server, a mobile device, or any other electronic device or computing system capable of receiving, sending, and processing data. In other embodiments, host device **202** and virtual tape library **204** represent a server computing system utilizing multiple computers as a server system, such as in a cloud computing environment. In an embodiment, host device **202** and virtual tape library **204** represent a computing system utilizing clustered computers and components (e.g. database server computers, application server computers, web server computers, etc.) that act as a single pool of seamless resources when accessed within network computing environment **200**. In general, host device **202** and virtual tape library **204** represent any programmable electronic device or combination of programmable electronic devices capable of executing machine readable program instructions and communicating with client device **208** and tape library **206** within network computing environment **200** via a network, such as network **210** and network **212**.

Virtual tape library **204** is a data storage system that includes a primary storage that acts as a cache for a secondary storage and virtualization software that presents a storage component (e.g., hard disk storage) as tape libraries or tape drives. Virtualizing disk storage as tape allows integration of virtual tape library **204** with existing backup software and existing backup and recovery processes and policies. For example, virtual tape library **204** may be an IBM TS7720 Virtualization Engine (TS7720 VE™) or an IBM 7740 Virtualization Engine (TS7740™). While reference is made to IBM-specific hardware and/or software components, it should be understood that aspects of the present invention may be applied equally to other virtual tape library technologies. In embodiments of the invention, virtual tape library **204** includes storage array **214** (i.e., disk array). For example, storage array **214** is a RAID (Redundant Array of Independent Disks) based storage system. In some embodiments, storage array **214** is composed of spinning hard disk drives ("HDDs"). In other embodiments, storage array **214** is composed of solid-state disk drives. Each disk in storage array **214** includes a disk cache, such as disk cache **216**.

In various embodiments of the invention, virtual tape library **204** receives write operations for data initially directed to be stored on a tape drive, such as a tape drive of tape library **206**. However, rather than directly writing the data to a tape drive of tape library **206**, virtual tape library **204** writes (i.e., "saves" or "stores") the data as a logical volume (i.e., virtual volume) on disk cache **216** of storage array **214**. The data may remain on disk cache **216** until removal of the data is required, at which point, the data is written to a tape drive of tape library **206**. For example, data is removed from a disk cache and written to a tape drive based on an amount of free space on the disk cache falling below and/or equaling a predetermined threshold value.

In various embodiments of the invention, virtual tape library **204** receives read requests. Upon receiving a read request, virtual tape library **204** determines whether the data is stored on a disk cache of storage array **214**. If the requested data is stored as a logical volume on a disk cache of storage array **214**, the data is read from the disk cache. However, if the requested data is stored on a tape drive of tape library **206**, virtual tape library **204** loads the data from a tape cartridge of tape library **206** to a disk cache of storage array **214**, such that the data is read from the disk cache.

Virtual tape library **204** includes data removal program **201** communicatively coupled to network **210** and network **212**. Although data removal program **201** is depicted in FIG. **2** as being integrated with virtual tape library **204**, in alternative embodiments, data removal program **201** is remotely located from virtual tape library **204**. For example, data removal program **201** can be integrated with host device **202**. Virtual tape library may include internal and external hardware components, as depicted and described in further detail with respect to FIG. **4**.

Tape library **206** is an automated tape storage device that includes a plurality of tape drives for writing to and reading from tape media, such as single-reel or two-reel magnetic tape cartridges. For example, tape library **206** may be an IBM TS3400™ Tape Library or an IBM TS3500™ Tape Library. While reference is made to IBM-specific hardware and/or software components, it should be understood that aspects of the present invention may be applied equally to other tape library technologies. In embodiments of the invention, tape library **206** includes a plurality of tape media stored in banks or groups of storage slots. For example, tape media may include, but is not limited to magnetic tape cartridges, magnetic tape cassettes, and optical tape cartridges. Tape library **206** further includes one or more tape drives, a plurality of slots to hold tape cartridges, a barcode reader to identify tape cartridges and an automated method (e.g., a robot) for loading tapes.

Client device **208** allows a user to access an application running on host device **202** and/or data removal program **201** via a network, such as network **210** and network **212**. Client device **208** may be a laptop computer, tablet computer, netbook computer, personal computer (PC), a desktop computer, a personal digital assistant (PDA), a smart phone, or any programmable electronic device capable of receiving, sending, and processing data. In general, client device **208** represents any programmable electronic device or combination of programmable electronic devices capable of executing machine readable program instructions and communicating with host device **202**, virtual tape library **204**, tape library **206**, and other computing devices (not shown) within computing environment **200** via a network, such as network **210** and network **212**.

Client device **208** includes user interface **218**. User interface **218** provides an interface between client device **208**, host device **202**, virtual tape library **204**, and tape library **206**. In some embodiments, user interface **218** may be a graphical user interface (GUI) or a web user interface (WUI) and can display text, documents, web browser windows, user options, application interfaces, and instructions for operation, and includes the information (such a graphic, text, and sound) that a program presents to a user and the control sequences the user employs to control the program. In other embodiments, user interface **218** may also be mobile application software that provides an interface between client device **208**, host device **202**, virtual tape library **204**, and tape library **206**.

FIG. **3** is a flow chart diagram depicting operational steps for data removal program **201** in accordance with at least one embodiment of the invention. FIG. **3** provides only an illustration of one implementation and does not imply any limitations with regard to the environments in which different embodiments may be implemented. Many modifications to the depicted environment may be made by those skilled in the art without departing from the scope of the invention as recited by the claims.

At step S**300**, data removal program **201** monitors one or more performance conditions of a disk cache, such as disk cache **216** of a storage array, such as storage array **214**. In some embodiments, monitoring a performance condition includes determining whether a performance condition falls below a predetermined threshold value. In other embodiments, monitoring a performance condition includes determining whether a performance condition exceeds a predetermined threshold value.

In embodiments of the invention, monitoring a performance condition includes determining an amount of free space (i.e., bytes) on disk cache **216** of storage array **214**. The amount of free space is relative to the size of the disk cache, which typically ranges from 128 MB in standard disks to 1 GB in solid state disks.

In embodiments of the invention, monitoring a performance condition includes determining a removal rate of logical volumes from disk cache **216**. In an embodiment, the removal rate of logical volumes is relative to the number of logical volumes that can be removed per unit of time (e.g., 5 logical volumes per second or 250 logical volumes per minute). In an embodiment, the removal rate of logical volumes is relative to an amount of data that can be removed per unit of time (e.g., 50 MB per second or 2,500 MB per minute).

In embodiments of the invention, monitoring a performance condition includes determining a rate at which data is written (i.e., write speed) to disk cache **216**. In some embodiments, the write speed is relative to the amount of data being written to a disk cache per unit of time (e.g., 150 MB per second). In other embodiments, the write speed is relative to the number of logical volumes being written to a disk cache per unit of time (e.g., **3** logical volumes per second). In an embodiment, the write speed is relative to a number of "private" logical volumes being written to a disk cache per unit of time. In an embodiment, the write speed is relative to a number of "scratch" logical volumes being written to a disk cache per unit of time. In an embodiment, the write speed is relative to a proportion of the number of "private" logical volumes and the number of "scratch" logical volumes being written to a disk cache per unit of time.

At decision step S**301**, data removal program **201** determines whether an amount of free space (i.e., storage space) on disk cache **216** is below and/or equal to a first predetermined threshold value (e.g., 25% free space). If an amount of free space on disk cache **216** is above the first predetermined threshold value, data removal program **101** returns to step S**300** (decision step "NO" branch). If the amount of free space on disk cache **216** is below and/or equal to the first predetermined threshold value, data removal program **201** proceeds to step S**302** (decision step "YES" branch).

At step S**302**, data removal program **201** performs a first automatic removal process for disk cache **216**. Under the first automatic removal process, data removal program **201** removes logical volumes in the scratch category in descending order of capacity (i.e., size). If all of the logical volumes in the scratch category are removed, data removal program **201** removes logical volumes in the private category in descending order of elapsed time of prior access. For example, a "private" logical volume accessed 20 minutes ago would be removed before a "private" logical volume accessed only 5 minutes ago.

At decision step S**303**, data removal program **201** determines whether the amount of free space (i.e., storage space) on disk cache **216** is below and/or equal to a second predetermined threshold value (e.g., 15% free space). It should be noted that the first threshold value in decision step S**301** and the second threshold value in decision step S**303** may be any predetermined numerical value, so long as the first threshold value is greater than the second threshold value. For example, the first threshold value corresponds to 20% free space on disk cache **216** and the second threshold value corresponds to 10% free space on disk cache **216**.

In embodiments of the invention, decision step S**303** is invoked during the first automatic removal process of step S**302**. For example, the amount of data being written to the disk cache **216** of storage array **214** may exceed the rate of removal of data in accordance with the first automatic removal process. Thus, if the amount of data being written to disk cache **216** exceeds the amount data being removed from disk cache **216**, the amount of free space on disk cache **216** can continue to decrease even though the first automatic removal process is occurring.

If the amount of free space on disk cache **216** is above the second predetermined threshold value, data removal program **201** returns to step S**301** (decision step "NO" branch). If the amount of free space on the disk cache is below and/or equal to the second predetermined threshold value, data removal program **201** proceeds to step S**304** (decision step "YES" branch).

At step S**304**, data removal program **201** predicts a removal rate per unit of time (e.g., bytes of data per second) for one or more "scratch" logical volumes stored on disk cache **216** of storage array **214**. In some embodiments, a first predicated removal rate is determined for the largest capacity "scratch" logical volume in accordance with the first automatic removal process ("scratch" logical volumes are removed in descending order of capacity). In these embodiments, the first predicated removal rate is based, at least in part, on: (i) a number of logical volumes that can be removed per unit of time and (ii) a capacity of the next logical volume slotted for removal.

In other embodiments, a second predicted removal rate is determined for two or more "scratch" logical volumes in accordance with the first automatic removal process ("scratch" logical volumes are removed in descending order of capacity). Thus, if the predicted removal rate is determined for three "scratch" logical volumes, the first logical volume would have the largest capacity, followed by the second and third logical volumes, respectively. In these embodiments, the second predicted removal rate is based, at least in part, on: (i) a number of logical volumes that can be removed per unit of time and (ii) an average capacity of two or more logical volumes slotted for removal.

In embodiments of the invention, whether data removal program **201** utilizes the first predicted removal rate or the second predicted removal rate is based, at least in part, on a length of time since the first automatic removal process was invoked. This is based on the assumption that the length of time that data has been removed from a disk cache will dictate a degree of similarity between those "scratch" logical volumes that remain on the disk cache. As the length of time increases, the degree of similarity in capacity size between the remaining "scratch" logical volumes stored on the data cache increases. This is based on the fact that data removal program **201** will continue to remove "scratch" logical volumes in descending order of capacity. Thus, after undergoing the first automatic removal process for a longer period of time, the "scratch" logical volumes that have a larger capacity will already have been removed, leaving the "scratch" logical volumes that have a smaller capacity on disk cache **216**.

On the other hand, as the length of time decreases, the degree of similarity in capacity size between the remaining "scratch" logical volumes stored on disk cache **216** decreases. This is based on the fact that data removal program **201** will continue to remove "scratch" logical volumes in descending order of capacity. Thus, after undergoing the first automatic removal process for a shorter period of time, a mixture of "scratch" logical volumes with various capacities are likely to remain on disk cache **216**.

In any of these embodiments, data removal program **201** analyzes historical automatic removal processes to determine a degree of similarity in capacity size of remaining "scratch" logical volumes stored on disk cache **216**. For example, data removal program **201** compares the length of time since the first automated removal process commenced to a previous automatic process invoked for a similar length of time to determine the degree of similarity between "scratch" logical volumes.

At decision step S**305**, data removal program **201** determines whether the rate at which data is being written to disk cache **216** is less than or equal to a predicted removal rate per unit time. In some embodiments, the determination is based on the first predicted removal rate. In other embodiments, the determination is based on the second predicted removal rate. If the rate at which data is being written to disk cache **216** is less than or equal to a predicated removal rate, data removal program **201** returns to step S**301** (decision step "YES" branch). If the rate at which data is being written to disk cache **216** is greater than a predicated removal rate, data removal program **201** proceeds to step S**306**.

At step S**306**, data removal program **201** performs a second automatic removal process. Under the second automatic removal process, data removal program **201** dynamically changes the priority of data removal from "scratch" logical volumes in accordance with the first automatic removal process to "private" logical volumes. In an embodiment, data removal program **201** removes logical volumes in the "private" category in descending order of capacity (i.e., size). In an embodiment, data removal program **201** removes logical volumes in the "private category" in descending order of elapsed time of prior access. In an embodiment, data removal program **201** alternates between removing logical volumes in descending order of capacity and logical volumes in descending order of elapsed time of prior access.

In some embodiments, removal of logical volumes in the "private" category in accordance with the second automatic removal process is based, at least in part, on whether a "private" logical volume stored on a disk cache virtual tape library **204** has been replicated on a disk cache of a second, distinct virtual tape library. It should be noted that cache misses may occur due to the removal of "private" logical volumes from the disk cache. Accordingly, if a cache miss occurs, the speed at which a "private" logical volume can be re-written to disk cache **216** of virtual tape library **204** is crucial to the performance of host device **102**. Since a logical volume can be obtained from another remote virtual tape library faster than from a tape library, such as tape library **206**, data removal program **201** may remove a "private" logical volume that is duplicated on another virtual tape library prior to removing a "private" logical volume that has not been duplicated on another virtual tape library.

At decision step S**307**, data removal program **201** determines whether the amount of free space on disk cache **216** is below and/or equal to the second predetermined threshold value. In some embodiments, data removal program **201** determines the amount of free space on disk cache **216** after each "private" logical volume is removed in accordance with the first predicted removal rate of the second automatic removal process. In other embodiments, data removal program **201** determines the amount of free space on disk cache **216** after two or more "private" logical volumes are removed in accordance with the second predicted removal rate of the second automatic removal process. If the amount of free space on disk cache **216** is above the second predetermined threshold level (decision step "NO" branch), data removal program **201** returns to decision step S**301**. If the amount of free space on disk cache **216** is below and/or equal to the second predetermined threshold level, data removal program **201** returns to step S**306**.

FIG. **4** is a block diagram depicting components of a computer **400** suitable for executing data removal program **201** in accordance with at least one embodiment of the invention. FIG. **4** displays the computer **400**, one or more processor(s) **404** (including one or more computer processors), a communications fabric **402**, a memory **406** including, a RAM **416**, and a cache **418**, a persistent storage **408**, a communications unit **412**, I/O interface(s) **414**, a display **422**, and external device(s) **420**. It should be appreciated that FIG. **4** provides only an illustration of one embodiment and does not imply any limitations with regard to the environments in which different embodiments may be implemented. Many modifications to the depicted environment may be made.

As depicted, the computer **400** operates over the communications fabric **402**, which provides communications between the computer processor(s) **404**, memory **406**, persistent storage **408**, communications unit **412**, and input/output (I/O) interface(s) **414**. The communications fabric **402** may be implemented with any architecture suitable for passing data or control information between the processor(s) **404** (e.g., microprocessors, communications processors, and network processors), the memory **406**, the external device(s) **420**, and any other hardware components within a system. For example, the communications fabric **402** may be implemented with one or more buses.

The memory **406** and persistent storage **408** are computer readable storage media. In the depicted embodiment, the memory **406** comprises a random access memory (RAM) **416** and a cache **418**. In general, the memory **406** may comprise any suitable volatile or non-volatile one or more computer readable storage media.

Program instructions for data removal program **201** be stored in the persistent storage **408**, or more generally, any computer readable storage media, for execution by one or more of the respective computer processor(s) **404** via one or more memories of the memory **406**. The persistent storage **408** may be a magnetic hard disk drive, a solid state disk drive, a semiconductor storage device, read-only memory (ROM), electronically erasable programmable read-only memory (EEPROM), flash memory, or any other computer readable storage media that is capable of storing program instructions or digital information.

The media used by the persistent storage **408** may also be removable. For example, a removable hard drive may be used for persistent storage **408**. Other examples include optical and magnetic disks, thumb drives, and smart cards that are inserted into a drive for transfer onto another computer readable storage medium that is also part of the persistent storage **408**.

The communications unit **412**, in these examples, provides for communications with other data processing systems or devices. In these examples, the communications unit **412** may comprise one or more network interface cards. The communications unit **412** may provide communications through the use of either or both physical and wireless communications links. In the context of some embodiments of the present invention, the source of the various input data may be physically remote to the computer **400** such that the input data may be received, and the output similarly transmitted via the communications unit **412**.

The I/O interface(s) **414** allow for input and output of data with other devices that may operate in conjunction with the computer **400**. For example, the I/O interface(s) **414** may provide a connection to the external device(s) **420**, which may be as a keyboard, keypad, a touch screen, or other suitable input devices. External device(s) **420** may also include portable computer readable storage media, for example thumb drives, portable optical or magnetic disks, and memory cards. Software and data used to practice embodiments of the present invention may be stored on such portable computer readable storage media and may be loaded onto the persistent storage **408** via the I/O interface(s) **414**. The I/O interface(s) **414** may similarly connect to a display **422**. The display **422** provides a mechanism to display data to a user and may be, for example, a computer monitor.

The present invention may be a system, a method, and/or a computer program product at any possible technical detail level of integration. The computer program product may include a computer readable storage medium (or media) having computer readable program instructions thereon for causing a processor to carry out aspects of the present invention.

The computer readable storage medium can be a tangible device that can retain and store instructions for use by an instruction execution device. The computer readable storage medium may be, for example, but is not limited to, an electronic storage device, a magnetic storage device, an optical storage device, an electromagnetic storage device, a semiconductor storage device, or any suitable combination of the foregoing. A non-exhaustive list of more specific examples of the computer readable storage medium includes the following: a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), a static random access memory (SRAM), a portable compact disc read-only memory (CD-ROM), a digital versatile disk (DVD), a memory stick, a floppy disk, a mechanically encoded device such as punch-cards or raised structures in a groove having instructions recorded thereon, and any suitable combination of the foregoing. A computer readable storage medium, as used herein, is not to be construed as being transitory signals per se, such as radio waves or other freely propagating electromagnetic waves, electromagnetic waves propagating through a waveguide or other transmission media (e.g., light pulses passing through a fiber-optic cable), or electrical signals transmitted through a wire.

Computer readable program instructions described herein can be downloaded to respective computing/processing devices from a computer readable storage medium or to an external computer or external storage device via a network, for example, the Internet, a local area network, a wide area network and/or a wireless network. The network may comprise copper transmission cables, optical transmission fibers, wireless transmission, routers, firewalls, switches, gateway computers and/or edge servers. A network adapter card or network interface in each computing/processing device receives computer readable program instructions from the network and forwards the computer readable program instructions for storage in a computer readable storage medium within the respective computing/processing device.

Computer readable program instructions for carrying out operations of the present invention may be assembler instructions, instruction-set-architecture (ISA) instructions, machine instructions, machine dependent instructions, microcode, firmware instructions, state-setting data, or either source code or object code written in any combination of one or more programming languages, including an object oriented programming language such as Smalltalk, C++ or the like, and conventional procedural programming languages, such as the "C" programming language or similar programming languages. The computer readable program instructions may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider). In some embodiments, electronic circuitry including, for example, programmable logic circuitry, field-programmable gate arrays (FPGA), or programmable logic arrays (PLA) may execute the computer readable program instructions by utilizing state information of the computer readable program instructions to personalize the electronic circuitry, in order to perform aspects of the present invention.

Aspects of the present invention are described herein with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems), and computer program products according to embodiments of the invention. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer readable program instructions.

These computer readable program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks. These computer readable program instructions may also be stored in a readable storage medium that can direct a computer, a programmable data processing apparatus, and/or other devices to function in a particular manner, such that the computer readable storage medium having instructions stored therein comprises an article of manufacture including instructions which implement aspects of the function/act specified in the flowchart and/or block diagram block or blocks.

The computer readable program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other device to cause a series of operational steps to be performed on the computer, other programmable apparatus or other device to produce a computer implemented process, such that the instructions which execute on the computer, other programmable apparatus, or other device implement the functions/acts specified in the flowchart and/or block diagram block or blocks.

The flowchart and block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various embodiments of the present invention. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of computer program instructions, which comprises one or more executable instructions for implementing the specified logical function(s). In some alternative implementations, the functions noted in the block may occur out of the order noted in the Figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts or carry out combinations of special purpose hardware and computer instructions.

The descriptions of the various embodiments of the present invention have been presented for purposes of illustration but are not intended to be exhaustive or limited to the embodiments disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the described embodiments. The terminology used herein was chosen to best explain the principles of the embodiments, the practical application or technical improvement over technologies found in the marketplace, or to enable others of ordinary skill in the art to understand the embodiments disclosed herein.

What is claimed is:

1. A computer-implemented method for maintaining a storage volume in a virtual tape system, the computer-implemented method comprising:

removing logical volumes that can be overwritten in priority to logical volumes that cannot be overwritten from a primary storage of the virtual tape system; and

switching from removing logical volumes that can be overwritten in priority to logical volumes that cannot be overwritten to removing logical volumes that cannot be overwritten in priority to logical volumes that can be overwritten based, at least in part, on:

an amount of free space on the primary storage being less than or equal to a second predetermined threshold.

2. The computer-implemented method of claim 1, wherein the removing logical volumes that can be overwritten in priority to logical volumes that cannot be overwritten comprises:

removing logical volumes that can be overwritten in descending order of capacity; and

removing, in response to removing all of the logical volumes that can be overwritten, logical volumes that cannot be overwritten in descending order of prior access.

3. The computer-implemented method of claim 1, wherein the second predetermined threshold is less than the first predetermined threshold.

4. The computer-implemented method of claim 1, wherein removing logical volumes that cannot be overwritten in priority to logical volumes that can be overwritten comprises removing logical volumes that cannot be overwritten in descending order of capacity.

5. The computer-implemented method of claim 1, wherein removing logical volumes that cannot be overwritten in priority to logical volumes that can be overwritten comprises removing logical volumes that cannot be overwritten in descending order of capacity.

6. The computer-implemented method of claim 1, wherein removing logical volumes that cannot be overwritten in priority to logical volumes that can be overwritten comprises removing logical volumes that cannot be overwritten in descending order of elapsed time of prior access.

7. The computer-implemented method of claim 1, wherein removing logical volumes that cannot be overwritten in priority to logical volumes that can be overwritten comprises alternating between removing logical volumes that cannot be overwritten in descending order of capacity and logical volumes that cannot be overwritten in descending order of elapsed time of prior access.

8. The computer-implemented method of claim 1, wherein selecting a logical volume that cannot be overwritten for removal is based, at least in part, on whether the logical volume that cannot be overwritten is replicated on a second virtual tape library.

9. The computer-implemented method of claim 1, wherein:

(i) the primary storage in the virtual tape system is a disk cache of a first virtual tape library and (ii) a secondary storage device in the virtual tape system is a tape drive of a tape library.

10. The computer-implemented method of claim 9, wherein the primary storage acts as a cache for the secondary storage in the virtual tape system.

11. The computer-implemented method of claim 1, wherein switching from removing logical volumes that can be overwritten in priority to logical volumes that cannot be overwritten to removing logical volumes that cannot be overwritten in priority to logical volumes that can be overwritten if further based, at least in part, on:

a rate at which data is being written to the primary storage being greater than or equal to a predicted removal rate of subsequent logical volumes that can be overwritten from the primary storage.

12. The computer-implemented method of claim 11, wherein the predicted removal rate of data for subsequent logical volumes that can be overwritten from the primary storage is further based, at least in part, on:

determining a first predicted removal rate based, at least in part, on: (i) a rate of removal of subsequent logical volumes that can be overwritten and (ii) a capacity of the largest subsequent logical volume that can be overwritten slotted for removal; and

determining a second predicted removal rate based, at least in part, on: (i) a rate of removal of subsequent logical volumes that can be overwritten and (ii) an average capacity of two or more subsequent logical volumes that can be overwritten slotted for removal.

13. A computer program product for maintaining a storage volume in a virtual tape system, the computer program product comprising one or more computer readable storage media and program instructions stored on the one or more computer readable storage media, the program instructions including instructions to:

remove logical volumes that can be overwritten in priority to logical volumes that cannot be overwritten from a primary storage of the virtual tape system; and

switch from removing logical volumes that can be overwritten in priority to logical volumes that cannot be overwritten to removing logical volumes that cannot be overwritten in priority to logical volumes that can be overwritten based, at least in part, on:

an amount of free space on the primary storage being less than or equal to a second predetermined threshold.

14. The computer program product of claim **13**, wherein: (i) the primary storage in the virtual tape system is a disk cache of a first virtual tape library and (ii) a secondary storage device in the virtual tape system is a tape drive of a tape library.

15. The computer program product of claim **13**, wherein the primary storage acts as a cache for the secondary storage in the virtual tape system.

16. A computer system for accelerated data removal for maintaining a storage volume in a virtual tape system, the computer system comprising:

one or more computer processors;

one or more computer readable storage media;

computer program instructions;

the computer program instructions being stored on the one or more computer readable storage media for execution by the one or more computer processors; and

the computer program instructions including instructions to:

remove logical volumes that can be overwritten in priority to logical volumes that cannot be overwritten from a primary storage of the virtual tape system; and

switch from removing logical volumes that can be overwritten in priority to logical volumes that cannot be overwritten to removing logical volumes that cannot be overwritten in priority to logical volumes that can be overwritten based, at least in part, on:

an amount of free space on the primary storage being less than or equal to a second predetermined threshold.

* * * * *